R10-TP-93

United States Department of Agriculture

Forest Service Alaska Region

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Biological Evaluation
July 2001

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Forest Health Protection Report

Changing Forest Structure and Composition in Glacier Bay National Park Long-term Spruce Beetle Mortality Plots

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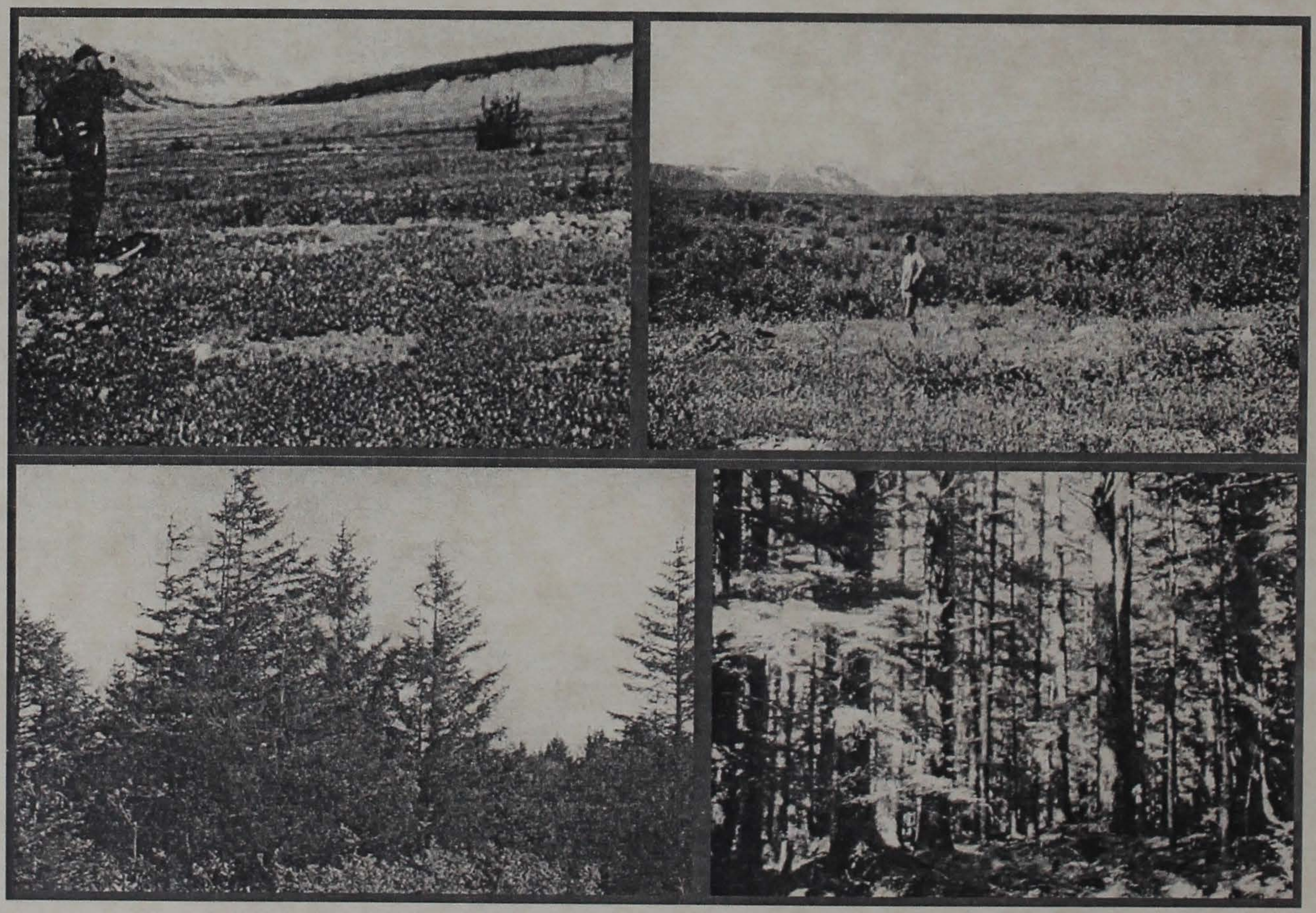

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Changing Forest Structure and Composition in Glacier Bay National Park Long-term Spruce Beetle Mortality Plots

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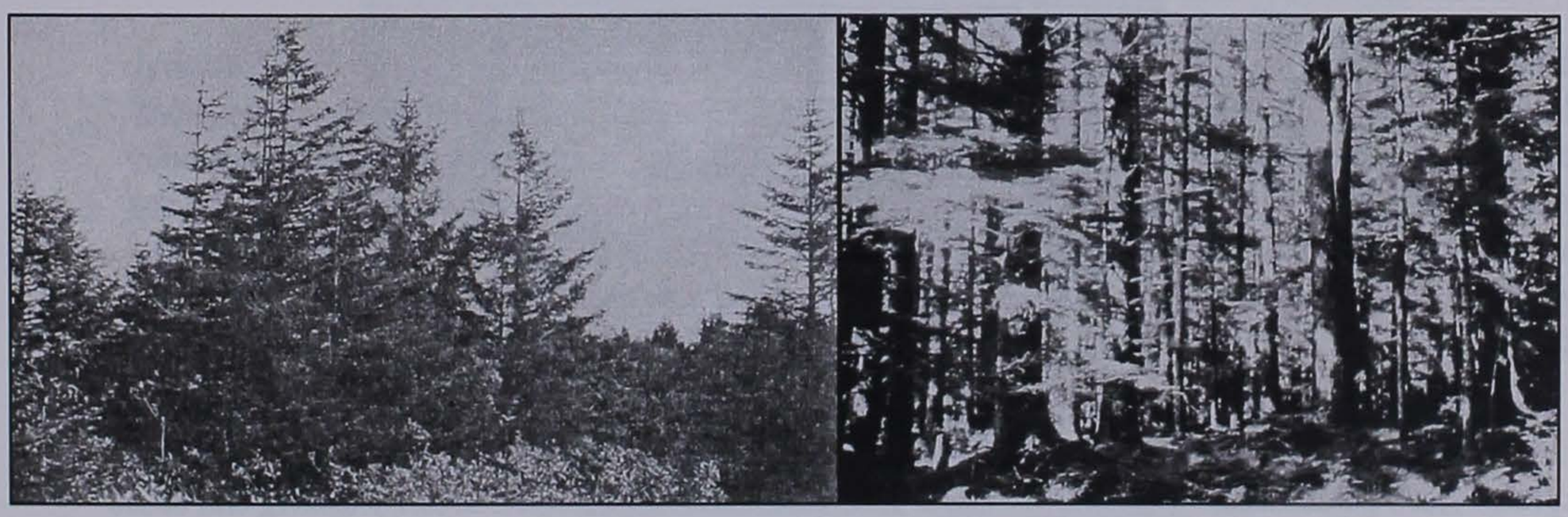
Introduction

Less than 200 years ago, the entire lowland area of Glacier Bay was covered with ice. Explorer Captain George Vancouver in 1794 found a retreating glacier at the mouth of Glacier Bay. That glacier was more than 4,000 feet thick, up to 20 miles or more wide, and extended more than 100 miles long (to the St. Elias Mountain Range). By 1879 the glacier had retreated 48 miles (noted by naturalist John Muir) and by 1916, 65 miles. Such rapid retreat is known nowhere else. The glacier terminus was estimated to be at the south end of Lester Island in 1794 (at the time of Captain George Vancouver's expedition to the bay). An old out-wash area was overlain by a terminal moraine in the Bartlett Cove area (Cooper 1939). Vast areas of bare land were colonized by primary-plant communities (Cooper 1923). Most sites go through a progression of species from low growing rock moss, horsetail, willow/herb, and *Dryas*,to shrubs (mostly willows), then alder, poplar, Sitka spruce, and lastly western hemlock underlain by sphagnum mosses (figure 1).

Soils of pioneer plant communities were usually low in nitrogen until the arrival of nitrogen-fixing plants. Lawrence, 1953 found that *Alnus* spp., *Dryas drummondii*, *Shepherdia canadensis*, and legumes increased the nitrogen content of glacial soils and prepared these soils for nitrogen-requiring invading plants. Pioneer Sitka spruce had suppressed growth (matted) and did not approach the height, diameter, and growth of Sitka spruce

Later stage Dryas drummondii 10 to 20 years after deglaciation (Goldthwait et.al. 1966. p. 119).

Alders have formed a dense thicket, interspersed with cottonwoods and willows in an area deglaciated for 15 to 35 years (Goldthwait et.al. 1966. p. 139).



These small stand of invading Sitka spruce stems (Strawberry Island: approximately 113 years after deglaciation, just north of Young Island) is actually multiple branches from one tree. Early invaders seldom become part of the dominant stand of Sitka spruce (Cooper 1923, figure 8).

Sitka spruce–western hemlock forest at Bartlett Cove deglaciated for more than 130 years (Goldthwait et.al. 1966. p. 141).

Figure 1. Successional stages of vegetation after glacial recession.

that come after this initial invasion. He found that black cottonwood (*Populus trichocarpa*) had an apical shoot increment five times greater in length and weight when growing near alder than when not. Crocker (same project) found that soil pH deceased quite rapidly on sites occupied by alder.

These sites were later occupied by Sitka spruce, which became the dominant vegetation only 75 years after the ice retreated. Now, the lower bay is occupied by relatively dense stands of slow growing Sitka spruce and western hemlock in the 120 to 140 year age class. Alaback 1981, reported that southeast Alaska stands reach their greatest bole wood production (productivity) at 100 years old and their maximum biomass at 120 to 130 years old. Bormann and Sidle, 1990, reported that in this age class Sitka spruce dominated stands in Glacier Bay began to loose their foliar nitrogen. Most of the nitrogen of this stand age was tied up in the 'O' (organic) soil horizon and above ground plant parts. This foliar nitrogen decrease was strongly correlated to the slowing of height and radial growth (productivity) over the last 50 years. Also, exchangeable macronutrients and micronutrients (except for iron) in the 'O' horizon were much lower in spruce stands than in alder stands.

Aided by nutrient immobilization (Cooper 1939), extensive blowdown in the late 1970s, and dry conditions in the early 1980s, a spruce beetle (*Dendroctonus rufipennis*) population began to build in 1980 (Anon 1983). Aerial photos taken in 1979 revealed spruce mortality on about 1,500 acres in the lower bay: on Young Island and Strawberry Island of the Beardslee Islands, and between Berg Bay and Ripple Cove west of the Beardslee Islands. The infestation spread dramatically between 1982 and 1985 (the epidemic years), was on the steady increase until 1997 and covered nearly 14,000 hectares in 1996. Spruce mortality exceeded 75 percent of the stand in some areas. Since 1995, spruce beetle mortality has occurred east of the original outbreak area, near Excursion Ridge.

The Forest Health Protection staff has provided technical assistance to Glacier Bay National Park since 1981. This assistance has included annual monitoring of the spruce beetle infestation and various training sessions to inform Park naturalists about the disturbance role of spruce beetle within the Park. Management strategies were developed and a hazard tree removal program has been initiated in areas of high visitor use. The Forest Health Protection staff has also been involved in cooperative research efforts with Pacific Northwest Institute of Northern Forestry and with the University of Minnesota.

The purpose of this paper is to report on changes that occurred in forest composition and structure by following 45 fifth-acre plots established in 1982 located at: Berg Bay, Ripple Cove, Young Island, Lester Island, north Bartlett Cove, and south Bartlett Cove.

Methods

In 1982, 45 fifth-acre plots (figure 2) were installed in the Sitakaday Narrows area of Glacier Bay National Park to record and report on the effect of a spruce beetle epidemic (Eglitis 1987). These plots were visited every year until 1988, and then in 1992 and 1998. The cause and date of tree mortality was retrospectively determined prior to 1982 as far back as 1976 by looking for evidence of mortality agents and assessing the amount of deterioration since tree death. In 1998, all plots were located using a small-scale map of their locations, the original field notes, aerial photos, and a compass. Tree data were collected on every tagged tree that could be found.

Basal area per hectare, trees per hectare, radial growth (1,081 Sitka spruce and 59 western hemlock increment cores), rate of tree death over time by cause of mortality, number and type of tree regeneration, and height of dead Sitka spruce were calculated for each plot. Basal area per hectare was calculated by taking the cross-sectional area of each recorded tree, multiplying by five (five fifth-acre plots per acre) and then multiplying that product by 2.47 (acres/hectare). The same multiplication factors were used to calculate the number of trees per hectare. Seedlings greater than two feet tall were counted and classified on a randomly chosen quarter section of 27 plots. A GPS location was taken at each plot center and all trees that could be assigned a tag number were stem-mapped.

All live trees were remeasured for height and diameter at breast-height (1.4 meters above the high side of the root crown). Stem breakage information (top breakage or windthrow) was collected for all tagged trees that could be found. Most dead trees were examined for old or new evidence of spruce beetle. When a diameter was not obtained for a tree during a remeasurement its diameter from an earlier date was used.

Cause of death was often difficult to determine for some of the trees but the use of tree mortality codes was used consistently. Notes taken on the 1982 to 1986 data forms were used to correct previous years data. From those notes it was possible to age mortality early in the epidemic, before the 1982 visit. Yearly percentages were determined from 1967 to 1982. Yearly mortality counts could not be as easily determined between 1987 and 1992, or between 1992 and 1998, so averages were used for those years. Some plots had extensive windthrow. The designation of windthrow killed in 1998 was given only for living trees that died from windthrow. All other down trees not windthrow killed were given a broken top killed designation.

Every tree could not be found in 1998. A tree was windthrow killed on the date it was found to be missing when neighboring trees were know to be windthrow killed. However, if there were no other windthrow killed trees in the plot and that tree went from green and alive to missing then it was classified as broken top killed. It was often hard to determine if the top died first before it broke. Generally, most of the broken boles were due to stem decay. Other cause(s) killed was used and not spruce beetle killed when not enough

Figure 2. Map of Glacier Bay National Park with insets of plot locations. Vegetation map produced by Pacific GIS. Insets produced by Dustin Wittwer.

spruce beetle adult and larval gallery length was observed. Unknown cause(s) killed was a designation used mostly for trees that died before 1977. Only in these cases was the inner bark too old to determine if spruce beetle galleries were present.

We collected height to break data for dead Sitka spruce. The time between tree death until it is on the ground was calculated differently depending upon the diameter of the tree. A broken-down tree (most of the bole on the ground) classification was given when less than 10 feet of a tree was standing for trees 5 to 12 inches diameter breast height, less than 20 feet of a tree was standing for trees 13 to 20 inches diameter breast height, and less than 30 feet of a tree standing for trees greater than 20 inches diameter breast height.

Results

Overstory Composition

Plots were originally installed within locations that were dominated by Sitka spruce (figure 3). Western hemlock amounted to only a very small amount of the total basal area. The smallest amount of western hemlock basal area was present on Young Island.

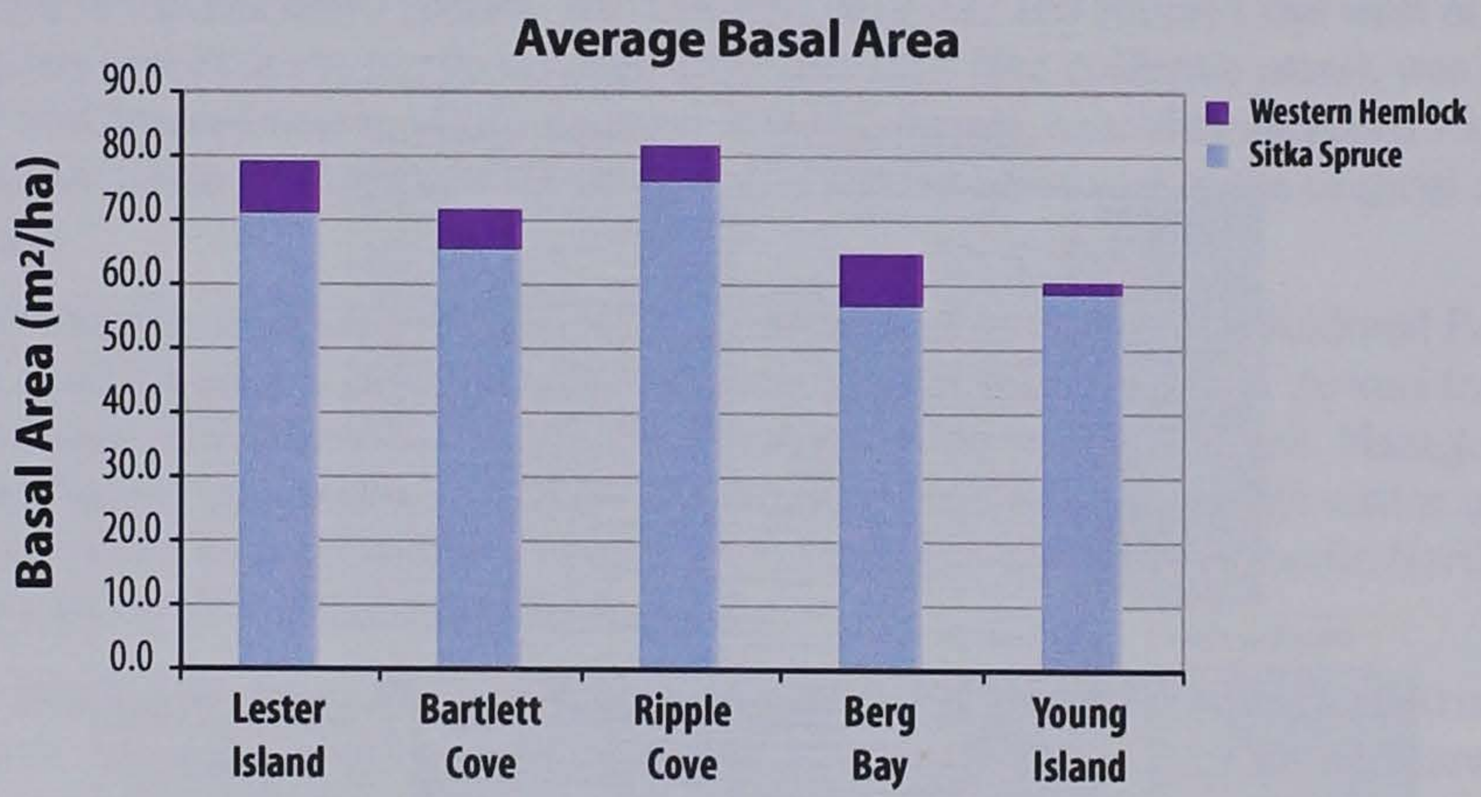


Figure 3. The average tree basal area of Sitka spruce and western hemlock for the five plot locations early in the outbreak (1977).

Tree Mortality and Basal Area Decrease

The difference in basal area from one date to another was the result of trees dying, the error of measuring diameter at breast height, and the diameter growth of residual trees. A majority of the increase in basal area between dates was due to the error of measuring tree diameter (tree growth was slow throughout the study).

Of the locations studied, the spruce beetle epidemic began first on Young Island (plot data presented here and from observations made on 1979 infrared aerial photos). Young Island plots lost half of the Sitka spruce and more than half of the basal area prior to 1982 (figures 4 and 5). Only 65 percent of the basal area of the Young Island plots remained by 1977. Lester Island plots lost more trees and basal area between 1982 and 1998 than plots at any of the other locations. Young and Lester Island plots had about the same average percent live trees in 1998, from one-third to one-half or less than plots at the other locations.

Figure 4. Average percent live trees for the five locations based upon data taken in 1982, '87, '92, and '98 and an estimated number of dead trees in 1977.

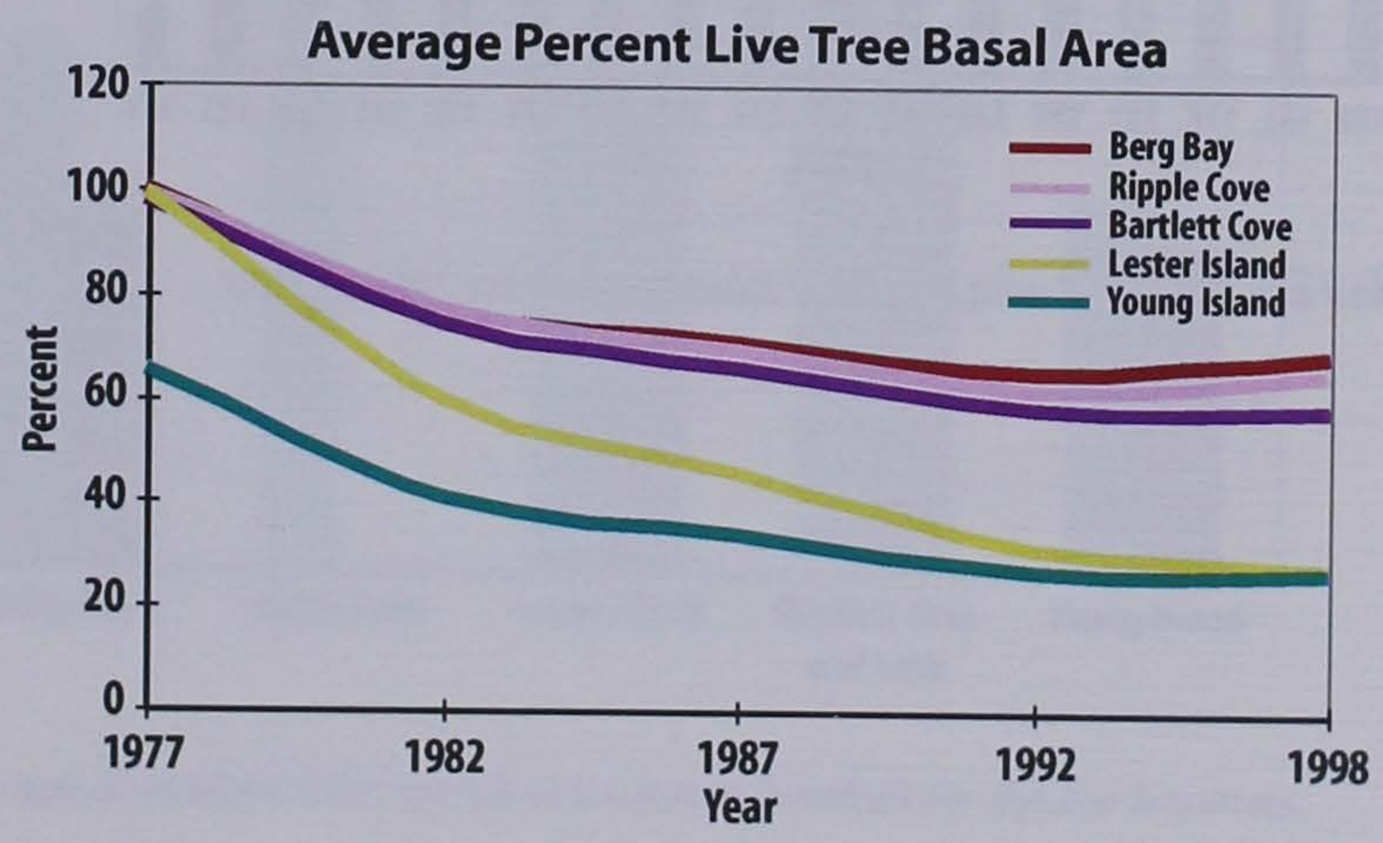


Figure 5. Average percent live tree basal area for the five locations based upon data taken in 1982, '87, '92, and '98 and an estimated number of dead trees in 1977.

Not all of the plots at each location followed the same tree mortality trend. Some of the greatest variation in tree mortality was recorded for the Lester Island plots (figure 6). The greatest percent decrease in basal area occurred between 1977 and 1982 for 13 of 18 plots. The second greatest decrease in percent basal area occurred between 1982 and 1987 for the other 5 plots. In 1998 70 percent of the basal area was in live trees for plot 116; less than 10 percent of the basal area was in live trees for plot 121.

For the Young Island plots after 1977 much of the reduction in live tree basal area occurred on three of the five plots (figure 7). The biggest decrease occurred before 1977. The second biggest decrease in percent live tree basal area occurred between 1977 and 1982 for one of the plots and between 1982 and 1992 for two of the plots. Only two trees died on all five Young Island plots between 1992 and 1998 and every plot had a slight increase in basal area. In 1998, over 60 percent of the basal area was in live trees for plot 144; less than 20 percent of the basal area was in live trees for plot 145.

The pattern of basal area decrease was similar for Ripple Cove, Berg Bay, and Bartlett Cove. Six-of-eight, five-of-eight, and four-of-five plots had the biggest decrease in live tree basal area between 1977 and 1982 for Ripple Cove, Berg Bay, and Bartlett Cove, respectively. The other two, three, and one plot(s) had the second biggest decrease in live tree basal area between 1982 and 1987 for Ripple Cove, Berg Bay, and Bartlett Cove, respectively.

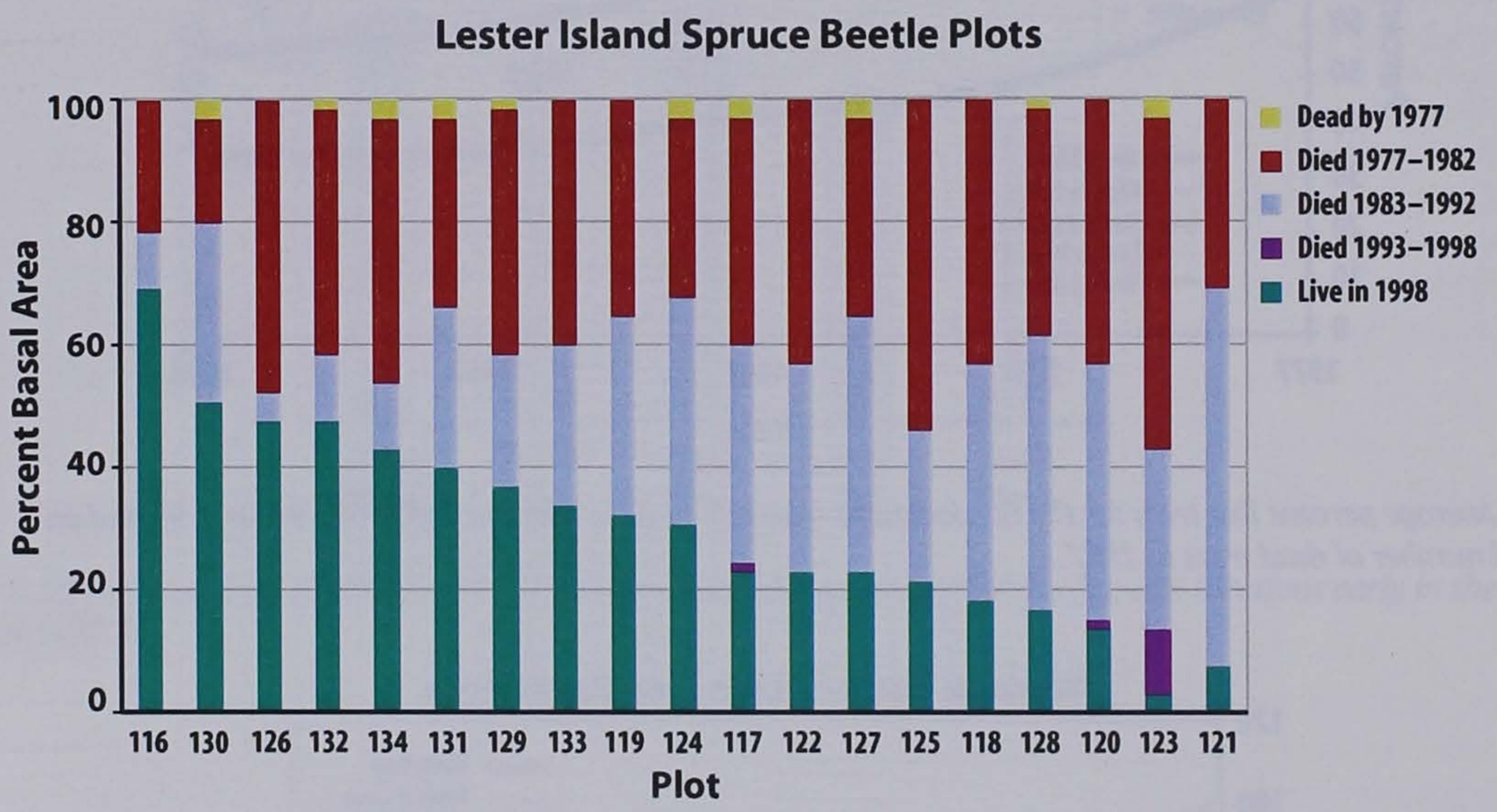


Figure 6. Change in percent live tree basal area on Lester Island plots from 1977 to 1998.

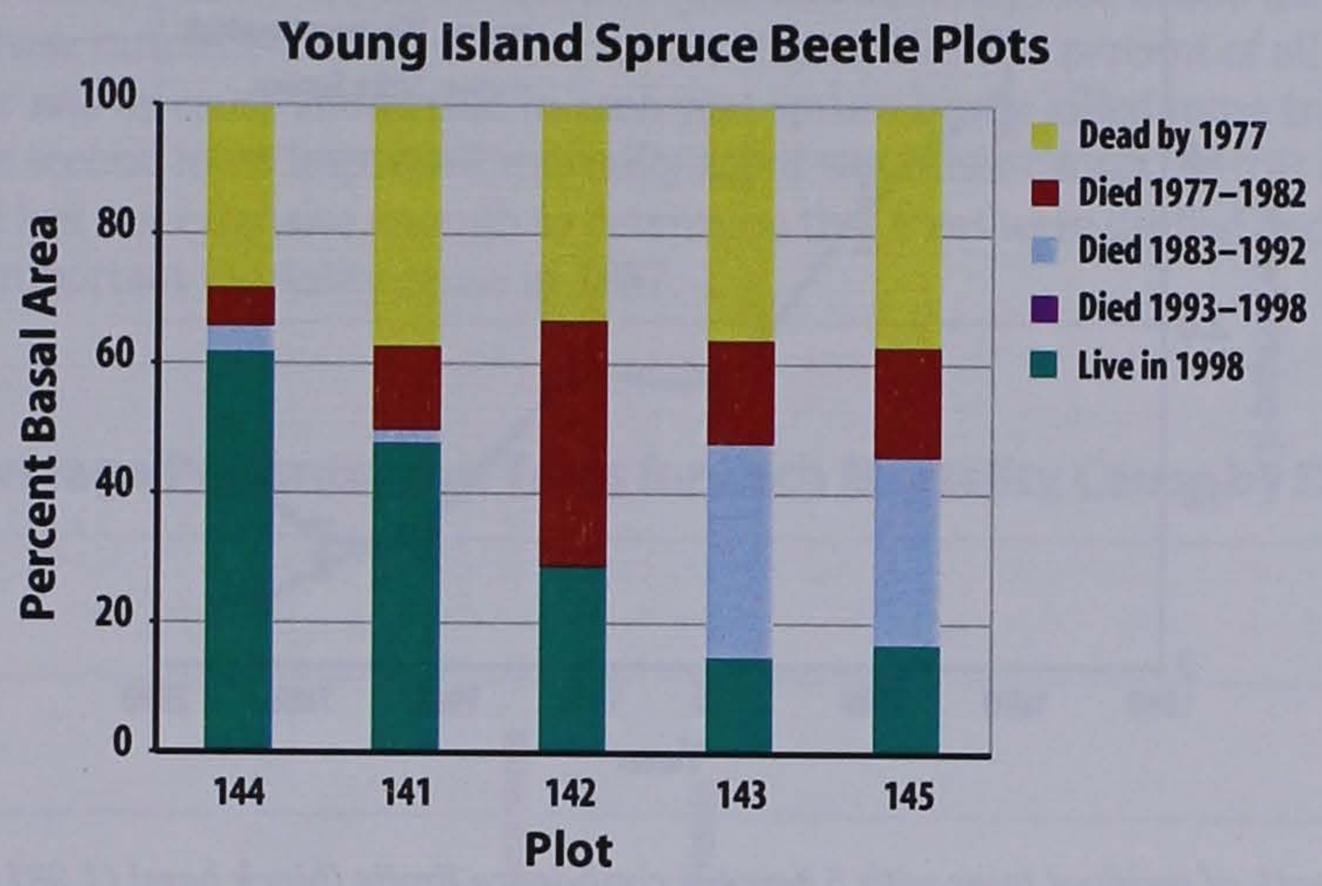


Figure 7. Change in percent live tree basal area for Young Island plots from 1977 to 1998.

Tree Age and Growth

Sitka spruce was older than western hemlock (figure 8). Sitka spruce colonized the glacial retreat areas after alder and willow (Cooper 1923). The youngest trees were on Young Island. Diameter growth of Sitka spruce was relatively good until 1940 when it rapidly declined (figure 9). By 1992 the radial growth of Sitka spruce was one-sixth of its radial growth in 1880. As the forest canopy opened up because of Sitka spruce mortality, the growth rate of western hemlock increased but not the growth of the Sitka spruce.

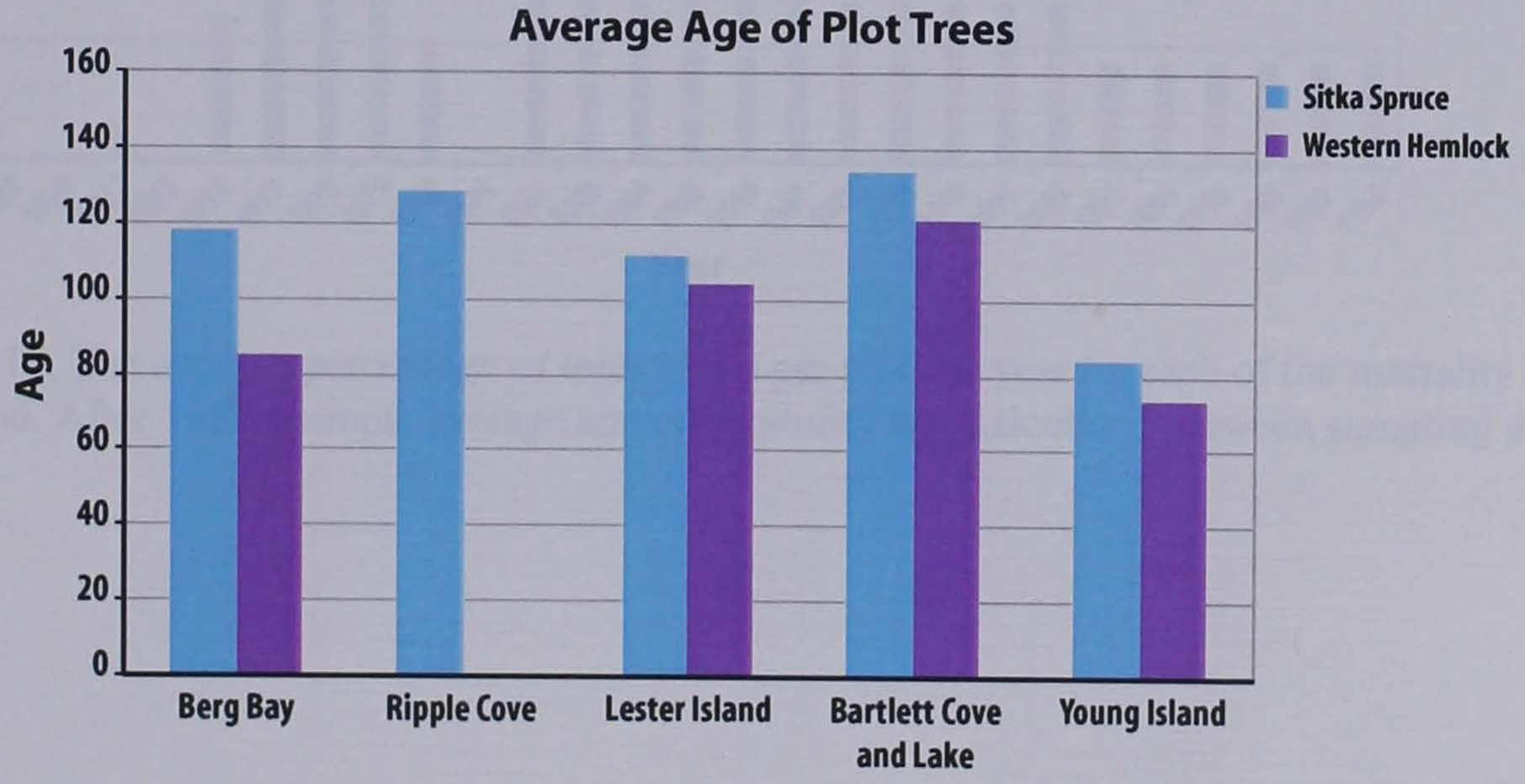


Figure 8. The average age of residual Sitka spruce and western hemlock for the five locations.

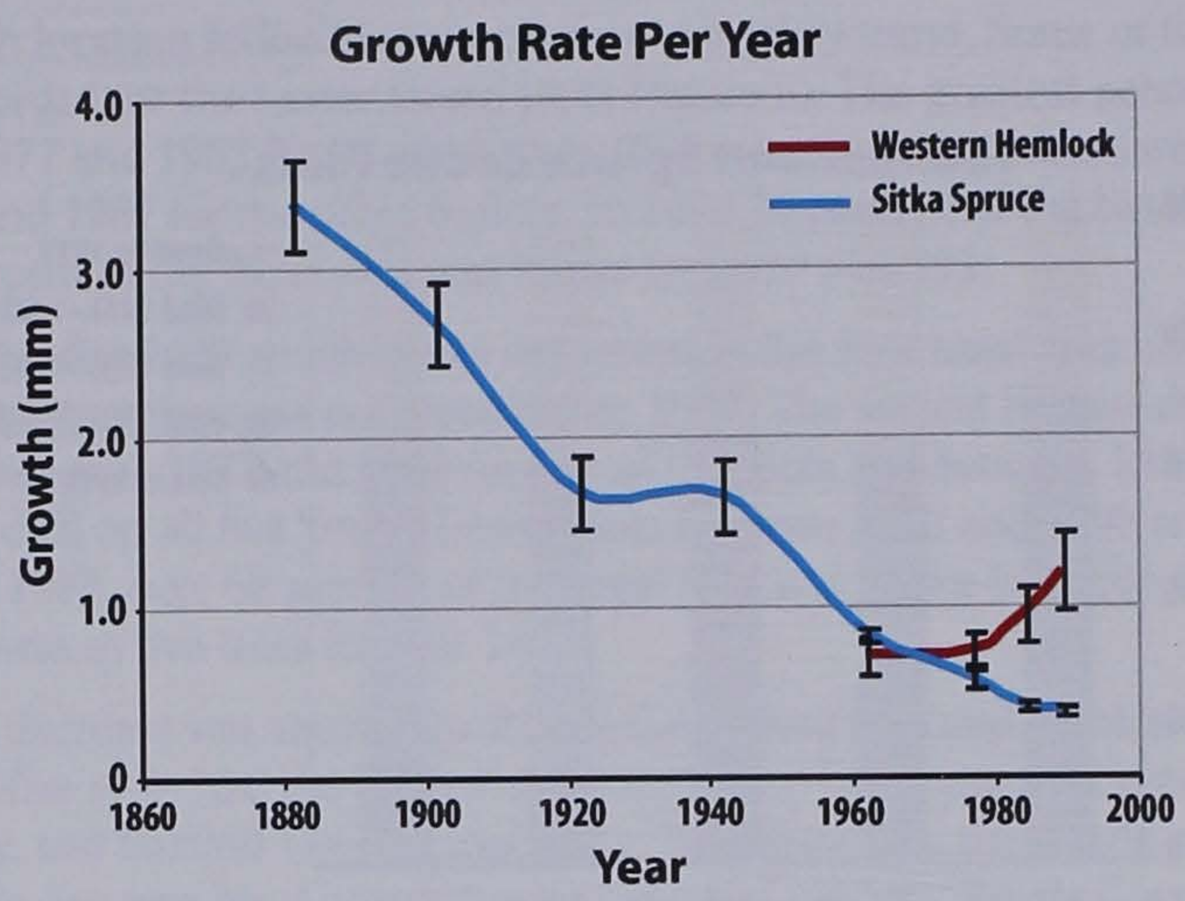


Figure 9. Mean radial growth of residual trees with 5 percent confidence limits (black bars) (1,081 Sitka spruce and 59 western hemlock).

Mortality Agents

Most of the Sitka spruce mortality occurred between 1981 and 1988. Spruce beetle was the most important mortality agent of these nutrient-weakened Sitka spruce (figure 10). The percent of all trees that died from 1967 to 1998 by year and by cause shows that in each year spruce beetle killed more trees than any other mortality agent. The second most important mortality agent was other-causes. In this case spruce beetle galleries were found but not extensive enough to determine that trees were girdled and killed by spruce beetle. Windthrow was an important mortality cause in 1987.

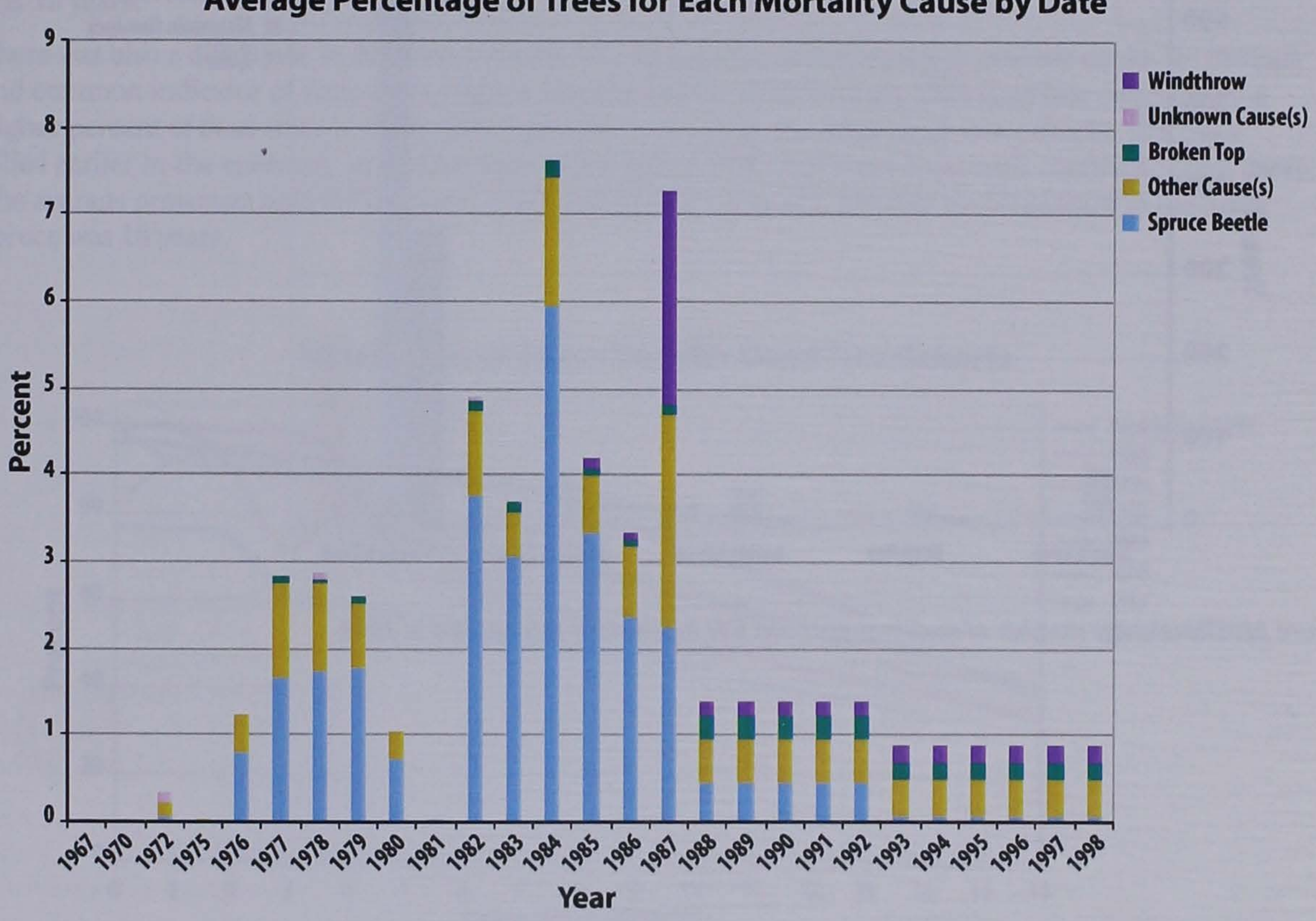


Figure 10. The average percentage of trees killed per plot per year by each of the mortality causes recorded. After 1987 a simple average annual mortality was calculated between sampling dates.

Regeneration

The Young Island site had the most and probably the earliest tree regeneration (figure 11). Though there appears to be fewer Sitka spruce than western hemlock every plot appears to be fully stocked. No attempt was made to find seedlings shorter than two feet tall because many of the plots were covered with large wood.

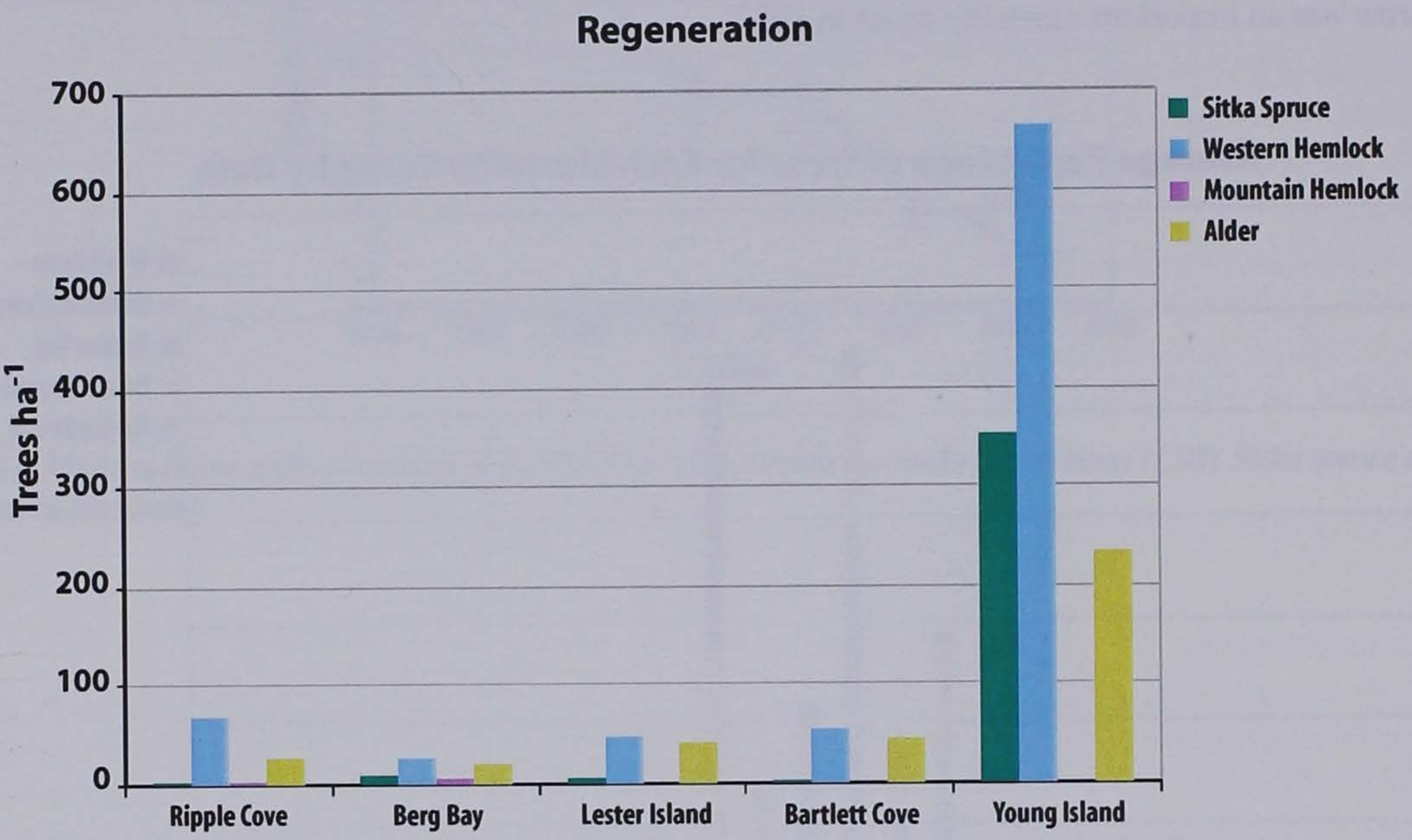


Figure 11. The average number of seedlings over two feet for the four tree species in 1998.

The Deterioration of Dead Sitka Spruce

Tree boles broke in a predictable way after tree death (figure 12). A higher percentage of the trees that died before 1985 broke within a few years of tree death than trees that died afterwards. There was no period with a similar high percentage of breakage for the 1985-87 dead tree cohorts. The average time between tree death and stem breakage for 50 percent of the Sitka spruce was 12 to 13 years.

As boles continued to break from the top down they decreased to a height were they remained quite stable for many years. A larger percent of trees that died in 1982 and earlier broke down from 1986 until 1998 than for the other dead tree cohorts (figure 13). The average projected time (no cohort reached 50 percent broken-down) between tree death and the boles being on the ground for 50 percent of the Sitka spruce was 20 years.

There was also a difference in dead tree cohorts for Sitka spruce with *Fomitopsis pinicola* conks, an obvious and common indicator of stem decay (figure 14). The before-1982 through 1984 dead tree cohorts had a higher percent of dead trees in 1998 with *F. pinicola* conks than the other dead-tree cohorts. The trees killed earlier in the epidemic, except for trees killed before 1982, had more trees with confirmed stem decay. The average projected time between tree death and visible conks of *F. pinicola* for 50 percent of the Sitka spruce was 18 years.

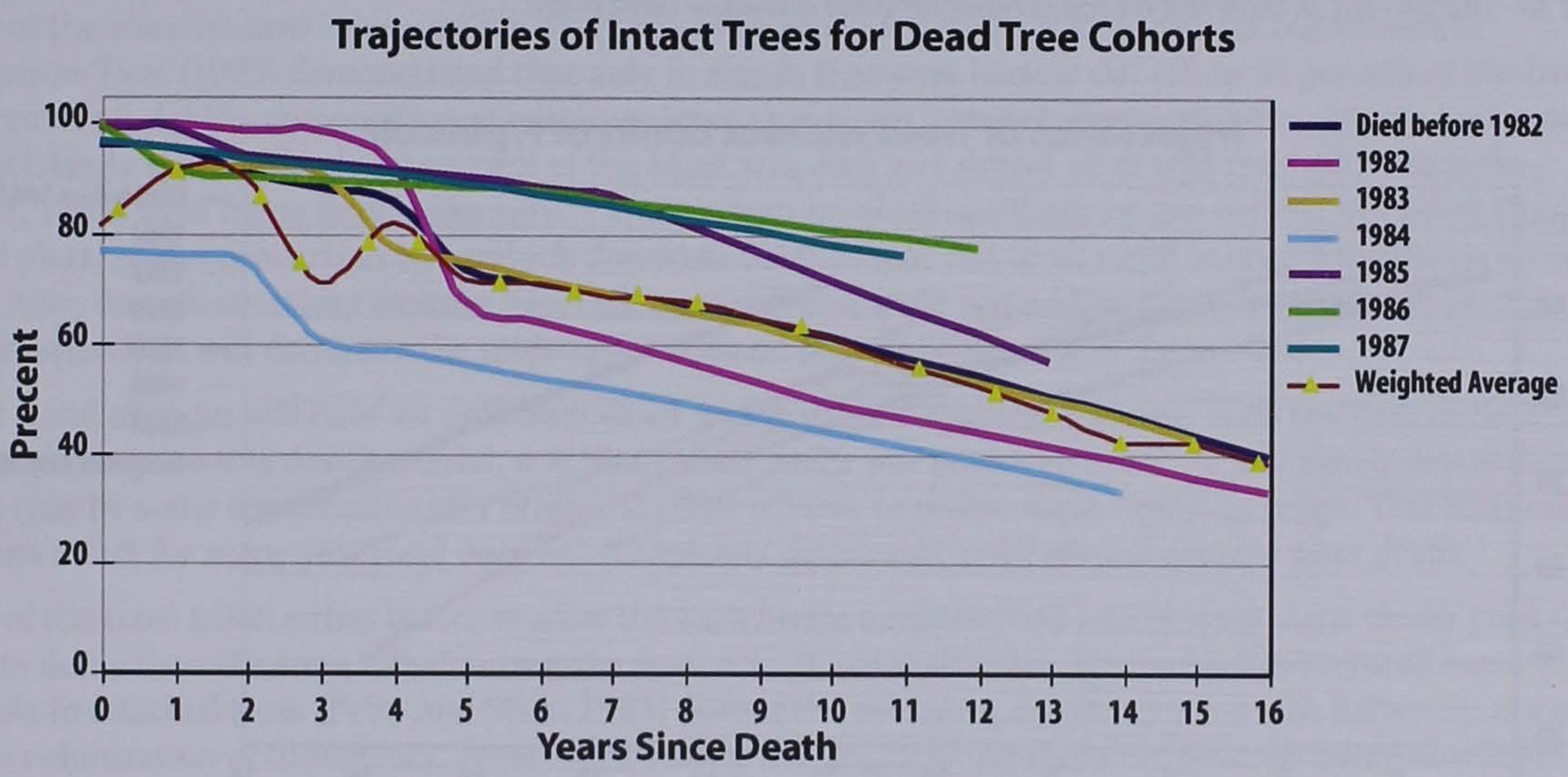


Figure 12. The percentage of trees not broken for each cohort of dead trees.

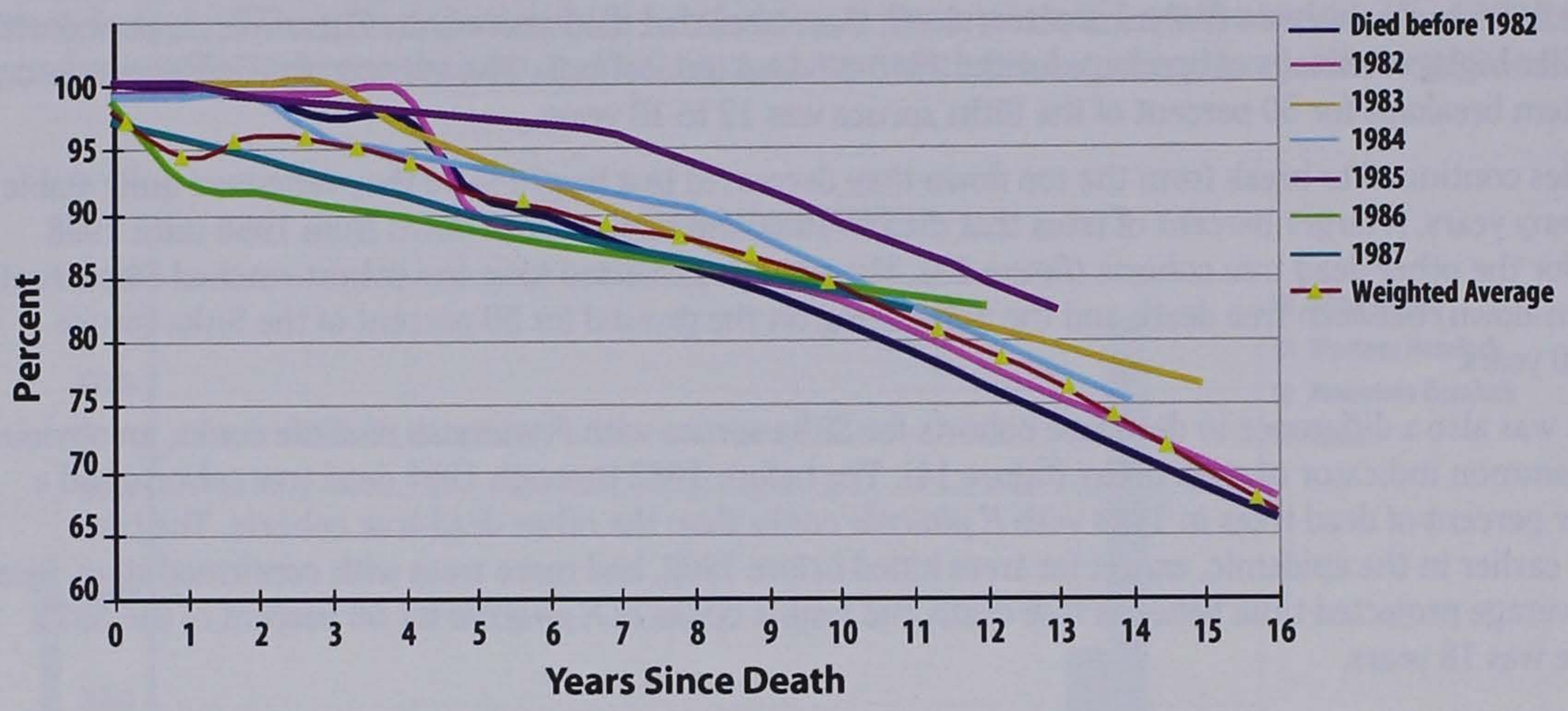


Figure 13. The percent of trees not on the ground for each cohort of dead trees.

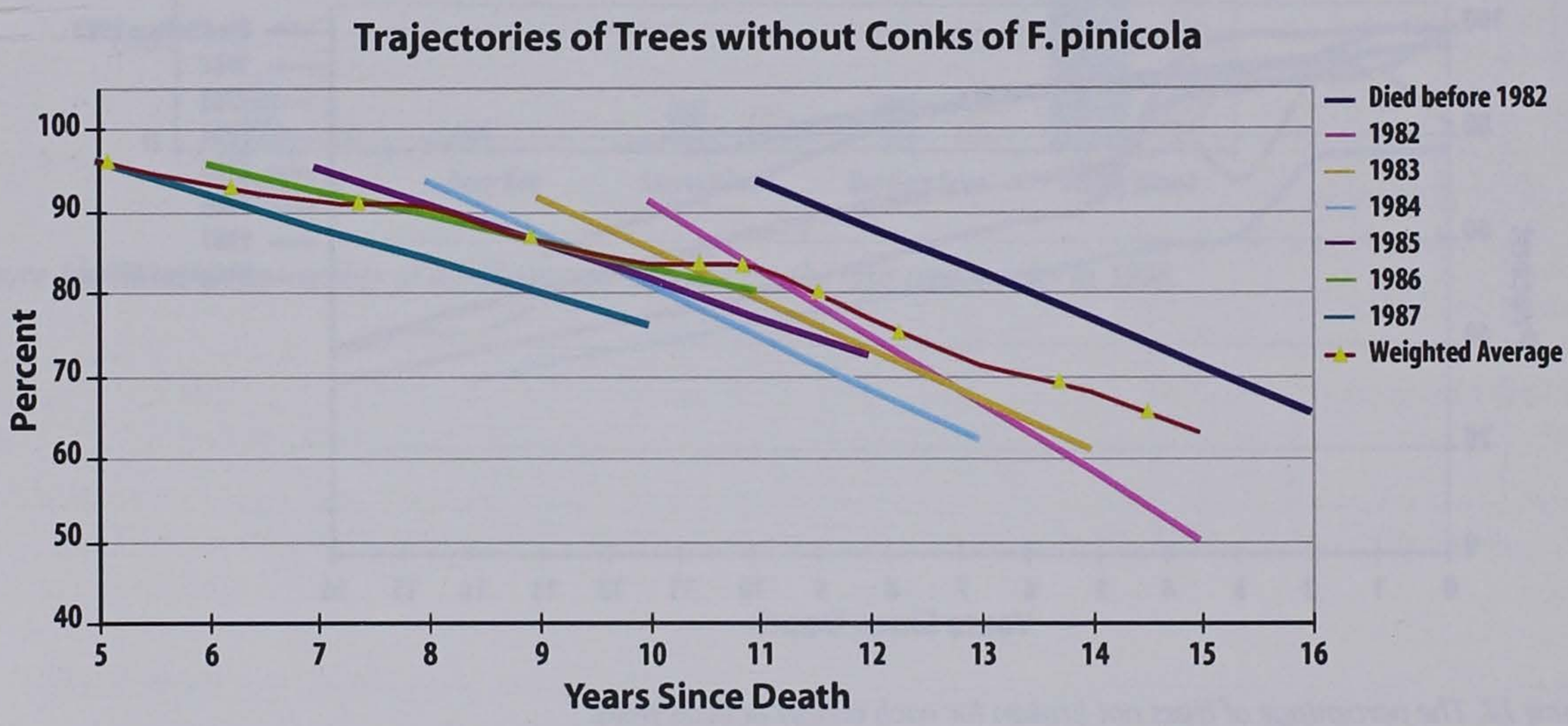


Figure 14. The percent of trees without Fomitopsis pinicola conks for each cohort of dead trees.

Discussion

Mature spruce forests are often attacked by spruce beetle in Alaska (Werner et. al. 1977). Beetle mortality was already present on Young Island before 1979. Blowdown was extensive throughout many spruce stands in southeast Alaska in the late 1970s resulting in even higher numbers of spruce beetle and in the large number of attacked and killed trees in the early 1980s. This outbreak has accelerated the conversion of infested stands toward stands that have the old-growth characteristics of canopy gaps and vegetation structure. If old-growth characteristics were desired, this outbreak could be viewed as a positive event accelerating stand development towards those characteristics.

Many interesting questions remain to be answered regarding spruce mortality in Glacier Bay National Park. Nutrient poor soil and building populations of spruce beetle were important factors of mortality. Spruce beetle has been associated with most of the dying spruce, but it is not the only contributing mortality agent. Spruce beetles were not found in many of the dead standing spruce.

These spruce dominated stands had a history of good growth that declined during a period of gradual stem exclusion and death of soil-nitrifying plants. A period of stable growth rate for Sitka spruce corresponded to a period (1921-1929) (Cooper 1931) when there was approximately 50 percent mortality of willow species. When soil nutrients were sequestered almost completely in the foliage and stems, annual radial growth slowed to one-half a millimeter.

Though a large number of trees died and were quite visible from the visitor center and park headquarters, many of the sites are now regenerating. Mortality of Sitka spruce may result in several trajectories of succession. Deal (1999) demonstrated that only in stands that were heavily cut (50 to 80 percent of the basal area removed) did the composition of overstory trees change (in hemlock-dominated stands). On Lester and Young Islands approximately 30 percent of the basal area died and almost all of that mortality was Sitka spruce. There were many large Sitka spruce and western hemlock seedlings on the earliest impacted Young Island plots, so the conversion to hemlock-dominated stands may not be as rapid as once believed on those plots. Also, though overstory western hemlock trees will dominate some sites, there is a cohort of spruce regeneration that will dominate the midstory canopy on at least 50 percent of these sites.

These stand changes will have an unknown effect on the wildlife that use the area. With few fires in Southeast Alaska to consume this dead material, it is likely these snags will gradually break up and slowly deteriorate. There may be some opportunities for birds and other wildlife to utilize these decaying snags. This material remains intact for many years and does not completely deteriorate until several decades after death.

More of the trees killed either before or after the bark beetle epidemic had less obvious signs (fewer conks) of stem decay than the trees killed during the epidemic. It is possible that spruce beetles vectored more F. pinicola to attacked trees (Petty and Shaw 1985) during the epidemic, resulting in a much better chance of fungal colonization of those trees. Trees killed during the height of the epidemic decayed faster, developed F. pinicola conks sooner, and became the large woody component of the forest floor sooner than trees that died from other causes before or after the outbreak.

This data set demonstrates the tremendous value in monitoring plots such as these on an annual basis during any epidemic of tree death. Annual measurements are necessary to properly address ecological questions. Data collected annually from 1982 until 1987 was the foundation of much of the results given in this document. A partial annual sample would have been better than a five-year gap of information. Plot designs and data collection must be futuristic in determining the kind of data that will be of value when plot data is analyzed. It is not practical to collect all ecological measurements, however, there are some quick estimates that can be quantitatively recorded for many relevant and related ecological indicators of change. It often takes a thorough review of project plans before the value of some of these indicators is realized.

ACKNOWLEDGEMENTS

Paul Hennon, Research Pathologist, S&PF and PNW has provided continuous intellectual as well as field support for this project. Andris Eglitis, Entomologist, Region 6 initiated and designed this project to fulfill a Glacier Bay National Park request for technical assistance. Roy Mask, Gunnison Service Center Leader, and Paul Reed, Iowa helped to collect the 1992 data. Dustin Wittwer, Biological Technician, helped to collect the 1998 data and produce the GIS generated graphs. Annette Untalasco, Computer Specialist, put the final touches on the document in rescanning the images and getting the graphs ready for printing. I also thank Paul Hennon, Jerry Boughton, Ed Holsten, and Lori Trummer and Dustin Wittwer for their comments and the review of the many versions of this report.

A special thanks to personnel of Glacier Bay National Park for providing all of us with housing and transportation.

REFERENCES

Alaback, P. 1982. Forest community structural changes during secondary succession in southeast Alaska. Pp 70-79. In: Forest succession and stand development research in the Northwest. Proceedings of a symposium on March 26, 1981. Corvallis, OR. Forest Research Laboratory, Oregon State University.

Anon. 1983. Forest insect and disease conditions in Alaska (R-10), 1981-1982. USDA. Forest Service, Alaska Region, Division of State and Private Forestry. 20 pp.

Cooper, W.S. 1923. The recent ecological history of Glacier Bay, Alaska: II. The present vegetation cycle. Ecology. 4(3):223-246.

Cooper, W.S. 1931. A third expedition to Glacier Bay, Alaska. Ecology, vol. 12(1). 61-95.

Cooper, W.S. 1939. A fourth expedition to Glacier Bay, Alaska. Ecology. Vol.20:2. 130-155.

Bormann, B.T. and R.C. Sidle. 1990. Changes in productivity and distribution of nutrients in a chronosequence at Glacier Bay National Park, Alaska. J. of Ecology. 78:561-578.

Deal, R.L. 1999. The effects of partial cutting on stand structure and growth, and forest plant communities of western hemlock-Sitka spruce stands in southeast Alaska. Ph.D. thesis. Oregon State University. 191 pp.

Eglitis, A. 1987. Spruce beetle in Glacier Bay National Park: 1986 Update. USDA Forest Service, State and Private Forestry, Forest Pest Management. 13 pp.

Goldthwait, R.P., et. al. 1966. Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska. The Ohio State University Research Foundation, Institute of Polar Studies. Report No. 20. August, 1966. 167 pp

Lawrence, D.B. 1953. Development of vegetation and soil on deglaciated terrain of southeastern Alaska with special reference to the accumulation of nitrogen. University of Minnesota, College of Sci., Lit., and Arts. Final Report, Project NR 160-183. 39 pp.

Petty, T.M. and C.G. Shaw. 1986. Isolation of *Fomitopsis pinicola* from in-flight bark beetles (Coleoptera: Scolytidae). Can. J. Bot. Vol 67. 1508-1509.

Werner, R.A, B.H. Baker, and P.A. Rush. 1977. The spruce beetle in white spruce forests in Alaska, USDA Forest Service General Technical Report PNW-61. 13 p.